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Paper Session II-A - Space Station Assured Crew Return Vehicle (ACRV) System and Operational Considerations

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SPACE STATION ASSURED CREW RETURN VEHICLE (ACRV) SYSTEM AND OPERATIONAL CONSIDERATIONS

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ABSTRACT

The Space Station currently is being designed to maximize crew safety through fault tolerance, safe-haven provisions, and crew delivery and return using the Space Transportation System (STS). Studies have identified the need for assured crew return capability through a space-based "lifeboat" that is always available for use in contingencies encompassing (1) medical emergencies, (2) Space Station failures, and (3) interruption of STS services. This paper reviews major mission, operational, and system requirements and the process for evaluating a range of practical vehicle and operational options. It describes flight and ground system design concepts and the major trade studies being performed to select the best end-to-end system that will provide a basis for design and development. Flight vehicles include capsules with ballistic and low lift/drag characteristics and lifting body aerodynamic-shaped designs. Ground systems emphasize the use of existing resources.

1. INTRODUCTION

During Space Station Phase B studies, consideration was given to enhancement of crew safety through the use of a space-based crew return vehicle. NASA initiated assured crew return capability studies in 1986 and assessed space- and ground-based crew rescue approaches. The NASA studies concluded that space-based rescue was required; this conclusion was supported by several major independent study groups, including the National Research Council, Aerospace Safety Advisory Panel, and the NASA Critical Evaluation Task Force activity at the Langley Research Center.

- OBJECTIVE — TO DEFINE AN ASSURED MEANS OF CREW RETURN FROM SPACE TO SUPPORT SPACE STATION PERMANENT MANNEDED PRESENCE
- ACRV STUDIES INITIATED IN FY 1986 FINALIZED FY 1988
- TWO APPROACHES ADDRESSED
 - SPACE-BASED — RESPOND IN MINUTES/HOURS
 - GROUND-BASED — RESPOND IN WEEKS/MONTHS
- IN-HOUSE ACRV STUDY CONCLUDED SPACE-BASED RESCUE SYSTEM WAS NECESSARY FOR DEFINED MISSIONS
 - CREW RETURN FOR MEDICAL REASONS
 - NEED FOR STATION EVACUATION
 - NSTS SERVICE INTERRUPTION
- CONCURRENT STUDIES BY VARIOUS INDEPENDENT GROUPS SUPPORTED THE NEED FOR SPACE-BASED RESCUE SYSTEM
 - 1987 NATIONAL RESEARCH COUNCIL REPORT
 - 1989 AEROSPACE SAFETY ADVISORY PANEL REPORT
 - CRITICAL EVALUATION TASK FORCE, ETC.

2. NASA ACRV STUDY PROCUREMENT PLANS BEING IMPLEMENTED

As a result of studies that identified the need for a space-based rescue system, NASA is contracting for ACRV systems studies.

Two contracts for combined Phase A' and optional Phase B studies are planned with durations of 6 and 12 months, respectively. These contract studies, each valued at \$6 million, commence in April 1990 under the management of the NASA JSC Project Office.

- COMBINED PHASE A' & PHASE B OPTION ON ONE CONTRACT
 - PHASE A' FIRST 6 MONTHS
 - PHASE B "HARD" OPTION ADDITIONAL 12 MONTHS
 - EXERCISE OPTION DURING PHASE A'
- FIRM FIXED-PRICE CONTRACTS PLANNED
 - ESTIMATED VALUE \$6M (PER CONTRACT)
 - PHASE A' — \$1.5M
 - PHASE B — \$4.5M
- START APRIL 1990
- RESPONSIBLE ORGANIZATION: ACRV PROJECT OFFICE — JOHNSON SPACE CENTER

3. MISSION REQUIREMENTS AND SYSTEM IMPACT DEFINED

The NASA studies identified three missions requiring return of the Space Station crew using an ACRV. The missions that are combined into sets to develop requirements encompass:

- Return of a sick or injured crew member
- Return of the complete Space Station crew following a need for evacuation
- Return of the crew following interruption of STS services

The most significant mission requirements that impact the system design include crew size,

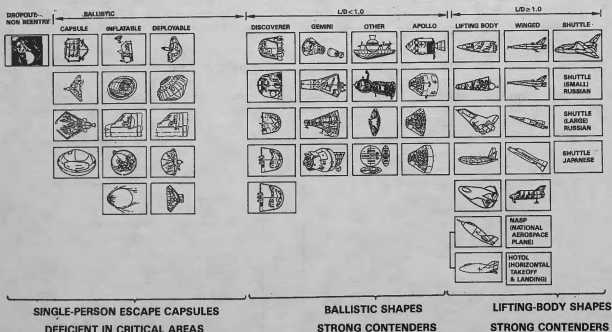
time constraints (including return of crew to a medical facility), and crew life support and acceleration limits. These key requirements influence the landing site selection; entry and landing modes; and the vehicle shape, size, number, and subsystem designs.

MISSION REQUIREMENT	SYSTEM IMPACT
MEDICAL MISSION <ul style="list-style-type: none"> • TIME LIMIT <ul style="list-style-type: none"> • 24 HR FROM DECISION • 6 HR MISSION • CREW ACCELERATION LIMITS • ENTRY • LANDING • SICK CREW 	LANDING SITE SELECTION & SAR CONTROLLED ENTRY MODERATE L/D CAPSULE OR LIFTING BODY IMPACT VELOCITY CONTROL MINIMUM CREW SIZE - 2 MEDICAL & EGRESS PROVISIONS
SS FREEDOM CONTINGENCY <ul style="list-style-type: none"> • EVACUATION TIME LIMIT • STATION CONDITIONS • CREW SIZE - 8 	GROUND SUPPORT & CHECKOUT ON-ORBIT OR GROUND LOTTER CAPABILITY CONTROLLED REPARATION VEHICLE SIZE/NUMBER OF VEHICLES
STS SERVICES INTERRUPTED <ul style="list-style-type: none"> • CREW SIZE - 8 	VEHICLE SIZE/NUMBER OF VEHICLES AS FOR STATION CONTINGENCY
COMBINED MISSIONS	NUMBER OF USES OVER 30 YEARS

4. WIDE RANGE OF CONCEPTS CONSIDERED

A wide range of concept options encompassing ballistic entry compatible shapes, controllable capsules, and aerodynamic lifting body vehicles

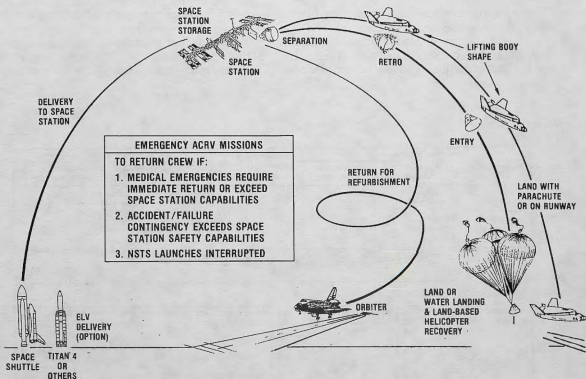
has been assessed relative to the ability of these systems to satisfy key mission requirements. Concepts have also been evaluated in terms of maturity and program impact to converge on the most promising representative configurations.



5. STUDIES PLANNED TO VALIDATE MISSION REQUIREMENTS AND ASSESS OPTIONS

Representative vehicle configurations in a range of aerodynamic performance categories are being evaluated in terms of their ability to satisfy

mission requirements and assure crew safety in an affordable system. A range of operating modes and system designs will be considered, encompassing ballistic and controlled entry; conventional parachute and parasail deceleration systems; and land terrain, water, or runway landings.



6. REPRESENTATIVE VEHICLES ASSESSED RELATIVE TO REQUIREMENTS

The assessment of representative vehicles is based on their merit relative to meeting mission or programmatic requirements and providing desirable system attributes.





Key mission requirements—including time constraints, crew size, and acceleration limits—are combined with the needs for simplicity, reliability, and cost effectiveness to establish desired system characteristics. These characteristics

encompass aerodynamic shape, automation, and control.

Representative systems are being assessed. Significant discriminators are the abilities to satisfy entry constraints, site access, complexity, and cost.

Of the candidate representative designs, only the ballistic entry capsule is incompatible with defined requirements due to the excessive acceleration experienced on entry. Major factors influencing the evaluation of remaining concepts include degree of complexity, maturity of the knowledge base and its impact on program risk, and the relative development and life-cycle costs.

MISSION REQUIREMENTS			CREW SAFETY • MINIMUM LCC & AFFORDABLE	SYSTEM CHARACTERISTICS DESIRED		
• CREW MEDICAL	• SPACE STATION EVACUATION	• STS SERVICES INTERRUPTED		• SIMPLE • RELIABLE	• AVAILABLE • ROBUST	• MAINTAINABLE • COST-EFFECTIVE
CREW: 3 MISSION: 24 HR TRANSPORT: 8 HR ENTRY g: -4 LANDING: 2-10	CREW: 4-8 EVAC: 15-30 M ENTRY g: -4 LANDING: 5-15	CREW: 4-8 ENTRY g: -4 LANDING: 5-15		<ul style="list-style-type: none"> • SICK CREW INFLUENCES AUTOMATION • CONFIGURATION PACKAGING SENSITIVE • DECONDITIONING INFLUENCES AUTOMATION • ENTRY g REQUIRES ENTRY LIFT • CONTROLLED LANDING REQUIRED 		

REPRESENTATIVE VEHICLES			
BALLISTIC WITH SEPARATE PROPULSION  <ul style="list-style-type: none"> • AUTOMATION DESIRABLE • ENTRY g INCOMPATIBLE • LANDING CONTROL REQUIRED • LOW COST • SIMPLE SYSTEMS • LOITER WITH SERVICE MODULE 	LOW L/D WITH INTEGRAL PROPULSION  <ul style="list-style-type: none"> • AUTOMATION DESIRABLE • ENTRY CONTROL • MODERATE CROSS RANGE • GOOD NSTS PACKAGING • LANDING CONTROL REQUIRED 	MODERATE L/D WITH SEPARATE PROPULSION  <ul style="list-style-type: none"> • AUTOMATION DESIRABLE • ENTRY CONTROL • GOOD CROSS RANGE • MARGIN ON ENTRY • MATURE DATA BASE • MAN-RATED CONFIGURATION • EXTENDED ON-ORBIT LOITER WITH SERVICE MODULE • 2 SHORTER PARAGLIDES • LANDING CONTROL REQUIRED 	HIGH L/D WITH INTEGRAL PROPULSION  <ul style="list-style-type: none"> • AUTOMATION DESIRABLE • ENTRY/LANDING CONTROL • LOW DECELERATION LOADS • MAXIMUM CROSS RANGE/SITE ACCESS • HORIZONTAL LANDING • NCDS TO RAISE LANDING L/D

7. RELATIVE PERFORMANCE ESTABLISHED AS A FUNCTION OF AERODYNAMIC SHAPE AND ENTRY MODE

The significant performance discriminators have been identified for the representative candidate concepts as a function of their hypersonic lift-to-drag ratio (L/D) and entry mode.

Ballistic entry capsule concepts offer potential for simplicity and low cost but are subject to high

entry g , higher temperatures, and larger recovery target dispersion, possibly necessitating water landing. Low to moderate L/D capsules with controlled entry offer the opportunity for lower entry g 's and temperatures, and smaller recovery targets with a resulting moderate increase in complexity and cost.

High L/D configurations provide lower entry g 's and temperature, excellent recovery target accuracy, and site access, but with significant increase in complexity and cost.

VEHICLE OR SYSTEM FACTOR	RANGE OF L/D				
	L/D = 0 BALLISTIC	L/D < 0.25	L/D < 0.5	L/D < 0.75	L/D > 1.1
	HIGH-G CONFIGURATIONS		LOW-G CONFIGURATIONS		
ENTRY (g's)	~8	>4	<4	<3	<2
GUIDANCE COMPLEXITY	SIMPLE, SPIN VEHICLE	BANK ANGLE CONTROL REQUIREMENT			<ul style="list-style-type: none">BANK ANGLE & α CONTROL REQUIRED FOR ENTRY3-AXIS CONTROL REQUIRED FOR RUNWAY LANDING
TRAJECTORY DISPERSIONS	LARGE ~ 30 NMI	L/D > 0.1 REQUIRED FOR GOOD TRAJECTORY CONTROL	1-NMI SPOT SIZE ACHIEVABLE		RUNWAY ACCURACY ACHIEVABLE
LANDING IMPLICATIONS	WATER ONLY	LAND OR WATER OPTION			RUNWAY LANDING IF SUBSONIC AERO CHARACTERISTICS ACCEPTABLE
CROSS RANGE IMPLICATIONS	EXTRA ΔV REQUIRED TO ACQUIRE LAND SITES, AERO CROSS RANGE INSUFFICIENT		AT L/D ≥ 0.5 SOME SITES ACCESSIBLE WITHOUT EXTRA ΔV	AT L/D ≥ 0.75 ALL SITES & CONUS-ACCESSIBLE WITHOUT EXTRA ΔV	ALLOWANCE OF EXTRA SITE ACCESS OPPORTUNITIES BY LARGE CROSS RANGE
HEATING IMPLICATIONS	INCREASING PEAK TEMPERATURE → INCREASING CONFIGURATION COMPLEXITY → INCREASING HEAT LOAD				
COST IMPLICATIONS	FROM DESIGN → FROM OPERATIONS →				

8. WATER IMPACT WITH PARACHUTE RECOVERY POTENTIALLY EXCEEDS CREW ACCELERATION LIMITS

Decisions on water or land landing and the landing system design are impacted by crew physiological acceleration limits that are orientation-dependent.

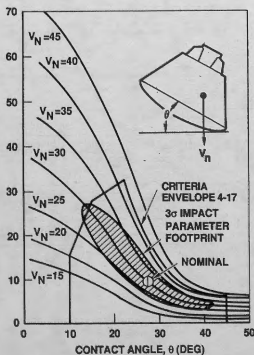
If a vehicle is landed in water, the induced acceleration environment is governed by vehicle shape, water penetration angle, vertical and hori-

zontal impact velocity components, parachute swing, roll orientation, and wave state.

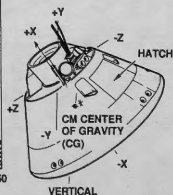
Experience with previous manned capsule programs using parachute recovery indicates that nominal acceleration on the order of 10 g's may be expected, with a range from 5 to 30 g's.

As this range of acceleration with a parachute recovery exceeds NASA-specified sick crew acceleration limits, controlled impact becomes necessary.

VEHICLE PEAK CG RESULTANT ACCELERATION (g's)



IMPACT ANGLE (TYPICAL)

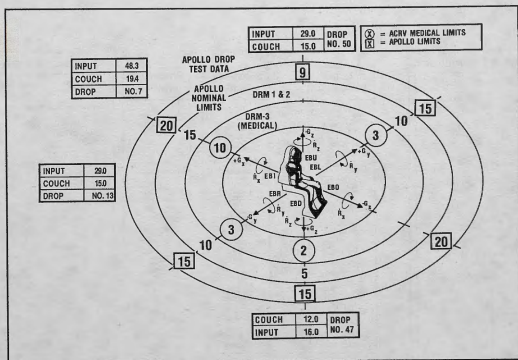


9. LAND IMPACT WITH PARACHUTE RECOVERY POTENTIALLY EXCEEDS CREW ACCELERATION LIMITS

A vehicle that is recovered on land will be subject to acceleration influenced by vertical and horizontal velocity components; dynamics on landing considering velocities, terrain, orienta-

tion; and vehicle shape and attenuation through vehicle and ground.

Experience with the Apollo program indicates that potential accelerations imposed on vehicle and crew will exceed the NASA-defined crew physiological limits. This indicates a need for reduction in velocity on impact.



10. ACRV OPERATIONS SUPPORT WILL EMPHASIZE USE OF EXISTING OR PLANNED RESOURCES

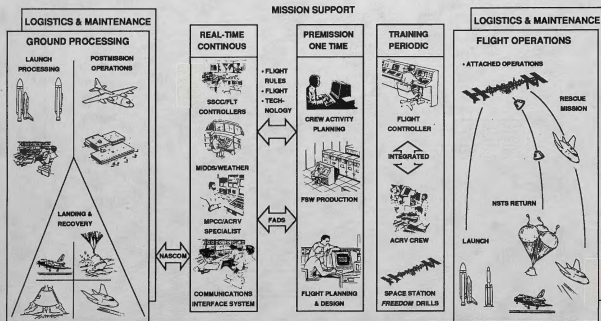
Key to effective and affordable operation of the ACRV are availability and cost effectiveness of operations resources for ground processing, mission support, and flight and recovery.

Ground segment affordability can be achieved through effective use of NSTS, SS

Freedom, expendable launch vehicles, payload processing facilities and resources, and existing search and rescue forces for ACRV recovery.

Mission support availability can be assured through shared use of existing and planned support resources, plans, and training programs.

Support to the flight segment will emphasize operational simplicity through use of existing support equipment inventories and technology.



11. MISSION AND SYSTEM TRADE STUDIES WILL RESULT IN SELECTION OF THE BEST ACRV SYSTEM

The selection of the best ACRV system to satisfy mission requirements in an affordable manner requires integrated trade studies to assess a range of system and operational options.

Major trade studies that influence system and

operation decisions have been defined, as illustrated in the matrix. These studies will be used in the derivation and definitization of ACRV requirements.

A consistent set of evaluation criteria are used to assess options to facilitate trade study decisions. These key evaluation criteria are satisfaction of mission requirements, crew safety, and life-cycle cost; affordability; simplicity; availability; reliability; and robustness.

INTEGRATED TRADES	VEHICLE CONFIGURATION		VEHICLE CREW CAPACITY		4-g CORRELATION ASSESSMENT		REUSABLE vs EXPENDABLE VEHICLE		LAND vs WATER LANDING		DAYTIME ONLY vs ANYTIME LANDING		ON-ORBIT vs LAND OR WATER LOITER														
	CAPSULE		LIFTING BODY	2 CREW	4 TO (8) CREW	6-9 g's	3-5 g's	2-4 g's	1-2 g's	SERVICE MODULE/PROPULSION		CAPSULE	WATER	LAND	RUNWAY	DAY OR NIGHT	DAYTIME ONLY	RECOVERY SITES			LOITER LIFE						
	BALLISTIC	MODERATE L/D								NUMBER OF SITES	RECOVERY DISTANCE (NM)							ON-SITE									
CONFIGURATIONS																		4+	3+	2+	100	25	ON-SITE	6 HR	18 HR	24 HR	
CAPSULE • BALLISTIC • LOW L/D • MODERATE L/D	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
LIFTING BODY			X	X	X			X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
<div><div><div>• SATISFIES MISSION REQUIREMENTS</div><div>• CREW SAFETY</div><div>• LIFE CYCLE COST</div><div>• AFFORDABLE</div><div>• SIMPLE</div><div>• AVAILABLE</div><div>• RELIABLE</div><div>• ROBUST</div></div><div>SYSTEM & OPERATION SELECTION</div></div>																											

12. ACRV WILL ENHANCE SPACE STATION CREW SAFETY THROUGH ASSURING A RETURN CAPABILITY

It is considered that a space-based rescue system will provide an effective means of assuring Space Station crew return.

Initial studies indicate that the ACRV system can be developed with current technology.

System cost may be minimized through use of available hardware and operations support resources.

Key to selection of the best system to satisfy needs are derivation and validation of mission

requirements and the application of consistent criteria to select the best end-to-end ACRV system and operations that assure crew safety and cost and operational effectiveness.

- ACRV REQUIRED TO ASSURE SPACE STATION CREW SAFETY
- LOSS OF SPACE STATION OR NSTS CREW WOULD HAVE MAJOR ADVERSE AFFECT ON OUR MANNED SPACE PROGRAM
- ACRV SYSTEMS DO NOT REQUIRE TECHNOLOGY ADVANCEMENT
- PROGRAM COST MAY BE MINIMIZED THROUGH USE OF AVAILABLE HARDWARE, SOFTWARE, & OPERATIONS SUPPORT RESOURCES
- CONCEPT SELECTION DRIVEN BY MISSION REQUIREMENTS, CREW CONSTRAINTS, & COST
- ACRV STUDIES SUPPORT SPACE STATION DECISIONS
- BUDGET DECISIONS REQUIRED FOR FY 1991 & FY 1992 ACTIVITIES